THE *SilvaGas*® PROCESS FROM FUTURE ENERGY RESOURCES -- A COMMERCIALIZATION SUCCESS

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ABSTRACT: The Burlington, Vermont gasifier is the first commercial scale demonstration of FERCO's *SilvaGas* indirectly heated biomass gasification process. The gasification plant is the largest operation of its type in the United States. The *SilvaGas* process was the first process to integrate a biomass gasifier with a gas turbine during pilot operations at Battelle's Columbus, OH facilities. The Burlington plant is coupled to the McNeil station of the Burlington Electric Department and is being used to evaluate and demonstrate the gasification technology both as a producer of fuel gas and in a combined cycle with a gas turbine power generation system.

The *SilvaGas* demonstration plant has achieved a number of significant milestones including demonstration that the process is very stable, can utilize feedstocks with moisture contents ranging from 10 to 50+%, produces a gas composition with a heating value of 11-14 MJ/Nm^3 (450 to 500 Btu/scf), and has high conversion efficiencies. These milestones have helped to validate the technology and provide a sound basis for discussions leading to the establishment of commercial projects around the world.

This paper discusses the operating results at the Burlington site including gasifier performance. The continued activities at the Vermont gasifier site and their impact on process improvements are discussed. Additionally the commercial development of additional projects based on the *SilvaGas* process is discussed.
Keywords: Gasification; biomass conversion, circulating fluidized bed

1 INTRODUCTION

In order to have the widest application today fuels derived from biomass must be interchangeable with conventional fossil fuels. Future Energy Resources (FERCO) has been developing a biomass gasification process that achieves this goal. The *SilvaGas* gasification process provides a means to convert a range of solid biomass fuels into a medium calorific value gas that can be directly substituted for natural gas or as an input for chemical synthesis applications. For gas turbine power applications, the use of biomass fuels provides a means to achieve high overall power generation efficiencies without introducing additional greenhouse gases to the environment. By converting the biomass into this high energy density gaseous fuel, significantly higher power generation efficiencies can be achieved relative to direct combustion based systems (approximately 40% power generation efficiency compared to a maximum of 25% with conventional biomass systems (HHV basis)).

2 PROCESS BACKGROUND

The Future Energy Resources Corporation (FERCO) *SilvaGas* biomass gasification process was developed to convert biomass into such a gaseous fuel. Unlike other biomass gasification processes, the FERCO process is not based on starved air combustion, but rather rapidly heats raw biomass in an air free environment to minimize tar formation and create a solid residue char that is used as a heat source for the biomass heating. Significantly less emissions are produced in the process because of the relative ease of treating the high energy density, medium heating value gaseous product.

The process is specifically designed to take advantage of the unique properties of biomass, such as high reactivity, low ash, low sulfur, and high volatile matter. The reactivity of biomass is such that throughputs in excess of 14,600 kg/hr-m^2 (3000 lb/hr-ft^2) can be achieved. In other gasification systems throughput is generally limited to less than 500 kg/hr-m^2 (100 lb/hr-ft^2). Other competing biomass gasification processes were either developed originally for coal gasification or were heavily influenced by coal gasification technology and therefore do not take full advantage of the properties of biomass.

2.1 The *SilvaGas* Process

The *SilvaGas* gasification technology underwent initial development at Battelle's Columbus Laboratories as a part of the DOE's Biomass Power Program. In the process, biomass is indirectly heated using a hot sand stream to produce a medium calorific value gas (approximately 17 to 19 /Nm^3 as is shown schematically in figure 1. The process uses two circulating fluidized bed reactors as the primary process vessels. The circulating sand is used as a heat transfer medium to rapidly heat the incoming biomass and convey char from the gasification reactor into the process combustor.

2.2 Technology Status

The process has been under development since the late 1970's and has been extensively tested with woody biomass, herbaceous crops (switch grass), prepared RDF from municipal wastes, and a variety of other waste biomass fuels. Testing in the 10 ton per day Process Research Unit (PRU), has coupled a Solar Spartan gas turbine (200 kW) power generation system to the PRU gasifier. This testing demonstrated the feasibility of biomass gasification for power generation, and has provided valuable design data for commercial scale process applications.

After over 20,000 hours of operation in the PRU, a commercial scale demonstration plant based on the *SilvaGas* process was constructed in Burlington, Vermont. Burlington Electric Department's (BED) McNeil station was selected as the site for this demonstration plant. BED has a long history with biomass based power generation. The McNeil station, at 50 MW, is one of the world's largest wood fired power stations. The McNeil station uses conventional biomass combustion technology, a stoker grate, conventional steam power cycle, and particulate removal using ESP's. BED hopes to improve its generating efficiency by implementing a gasification combined cycle system.

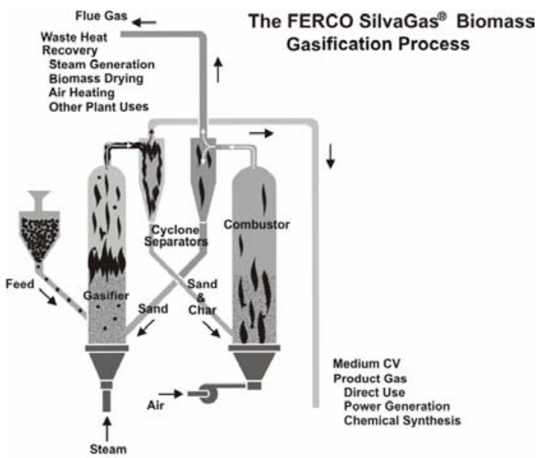

Figure 1: The *SilvaGas* Gasification Process

2.3 A Commercial Scale Demonstration Plant

The commercial scale demonstration of the ***SilvaGas*** process underway at the McNeil Generating station in Burlington, Vermont was designed for 182 dry tonnes (200 tons) per day of biomass feed. The gas produced is being used as a co-fired fuel in the existing McNeil power boilers. In subsequent phases of the program, a gas combustion turbine is planned to be installed to accept the product gas from the gasifier and confirm the results from the PRU testing.

The program has been conducted in three phases, (1) design, (2) construction and initial operation firing the product gas in the McNeil boiler, and (3) additional gas cleanup, gas compression, and operation of a gas turbine power generation system.

2.4 Development Partners

The partners in the development of the process at the McNeil site are FERCO, Burlington Electric, Battelle, the US DOE, and the National Renewable Energy Laboratory (NREL). Battelle engineers invented the process and conducted the initial developments under contract to the US DOE in the early 1980's. In 1992, FERCO purchased the rights to the technology from Battelle and is now the owner of the worldwide rights. FERCO is developing renewable energy projects based on the gasification technology worldwide. These projects will build on the operations at Burlington.

2.5 Program Goals and Objectives

The development program at McNeil has as its primary objective the demonstration, at full commercial scale, of the *SilvaGas* gasification process and associated support technologies. These technical goals parallel the Department of Energy's goals for bioenergy and the progress made by the Vermont Gasification project establishes thermal gasification as a key element for future development of biomass derived products by providing flexibility for the production of a complete slate of products as described above in a virtual "biomass refinery". The design of the plant includes all key process systems, with the exception of heat recovery.

The first operation of the Vermont gasifier in full steam gasification occurred in August of 1999. During the startup period, numerous design and operational changes to the plant were necessary to improve the performance of process auxiliary systems such as materials handling, solids separation, and scrubbing. No problems with the core process were encountered throughout the startup period.

Testing of the process and additional plant modification continued in early 2000. Continuous around-the-clock operation at the plant was achieved in August of 2000 and parametric testing at the site has produced positive operating results consistent with those previously achieved in the PRU. As is the case with all development scale projects, some minor equipment modifications continue at the Burlington site.

Figure 2: The Vermont Gasification Plant

3 OPERATING RESULTS

Immediately following the initial around-the-clock test period, a series of "parametric" tests was undertaken to evaluate key process parameters such as wood feed rate, effect of wood moisture content, effect of wood particle density, and effect of combustor excess air. In addition, these tests allow for the performance of the system to be monitored over extended around-the-clock operating periods. At the conclusion of each of the parametric testing periods as well as the initial "24-hour" test, the unit was shut down in a controlled manner according to the prescribed operating procedures. Tests were concluded when the specific feedstock(s) for that test campaign were exhausted. The Vermont gasifier is a demonstration facility and, as such, is only operated for specific experimental campaigns, rather than in a "production mode".

Throughout the testing campaigns, the plant operation has been very smooth and reliable. The plant has been demonstrated to operate stably and reproducibly over a range of process conditions. The following sections summarize the results of these tests and their impact on FERCO commercialization activities.

3.1 Product gas composition

Primary among these accomplishments is the demonstration of the production of a product gas with essentially the same composition and production rates as the projections made based on pilot scale data generated at Battelle.

Table 1 illustrates the composition of the product gas generated in the PRU compared to the gas currently being generated in the McNeil gasifier. The verification of the gas composition at commercial scale makes possible the commercial application of the *SilvaGas* process as a direct substitute for natural gas in direct-fired or gas turbine applications. The product gas composition remains stable in the *SilvaGas* process regardless of changes in feedstock

type, ash content, or moisture content. This characteristic of the process had previously been demonstrated during pilot operation at Battelle and has been verified through the current testing program in Vermont. As shown in figure 3, with the *SilvaGas* process, the gas quality is unaffected by fuel moisture. During the 24 hour period of operation shown, incoming wood moisture ranged from 10% to 50%.

In any biomass gasification system, the moisture content of the biomass feed is important. With partial combustion systems biomass moisture affects the product gas quality because more energy must be supplied to the gasifier to evaporate increased moisture in the feedstock thereby increasing carbon dioxide content of the produced gas increase with fuel moisture. Likewise, carbon monoxide decreases changing the heating value, mean molecular weight, and flame speed, as well as affecting the overall gasification efficiency. With the *SilvaGas* process, the increased energy requirement is provided by the circulating sand phase so gas composition remains unchanged. The process efficiency drops as a result of supplying this additional heat, but system response is sufficiently rapid to allow the adjustment of incoming biomass feed rate to compensate for the smaller quantity of product gas produced.

One obvious way of maximizing overall process efficiency is to utilize process waste heat in the process flue gas to dry the incoming biomass feed. Depending on site specific conditions and requirements, this waste heat can alternatively be used to heat air, raise steam, or for other process heating applications.

3.2 Reactor Throughput

The throughput of the *SilvaGas* process as discussed above, is significantly higher than competing gasification process. These high throughputs have the impact of providing compact reactor systems that can be readily incorporated into industrial or utility sites. Recent testing at the McNeil gasifier has demonstrated the ability of the process to achieve throughputs far in excess of even those previously predicted. Higher throughputs will result in lower relative capital costs and therefore further improvements in process economics.

The design capacity of the McNeil gasifier is 182 dry tonnes (200 tons) per day. Tests were run to evaluate the maximum throughput of wood to the plant. These tests showed that wood feed rates of over 320 tonnes per day (350 tons) could be achieved with no degradation in system performance as measured by gas composition and production rate. Higher feed rates were limited by the capacity of the feed system in the plant. Modification to the plant's feed system are planned to allow throughputs beyond 320 tonnes per day to be evaluated. These results indicate that plant turndown capability is at least 1.5 to 1.

3.3 System response

The *SilvaGas* process uses short residence time circulating fluidized bed reactors for both the gasification and combustion systems. As a result, the system can respond rapidly to changes in feed rate, wood moisture level, or feedstock type. The parametric testing program carried out in the Vermont gasifier has confirmed the ability of the *SilvaGas* process to rapidly respond to process changes or upsets. During the testing program, as feedstocks moisture levels were changed from one level to another, the gasifier and combustor reactors responded within minutes to the changes. Likewise, incoming wood feed rates can be changed as rapidly as required to match load requirements. This rapid response to process changes allows adjustment of incoming biomass feed rate to compensate for changes in the volume of product gas produced as feedstock moisture changes.

Table 1: Comparison of Burlington Gas Composition and Higher Heating Value to Battelle Pilot Data

Vol. %	Pilot Data	McNeil Data
H_2	17.5	22.0
CO	50.0	44.4
CO_2	9.4	12.2
CH_4	15.5	15.6
C_2H_4	6.0	5.1
C_2H_6	1.1	0.7
MJ/Nm^3	18.5	17.3

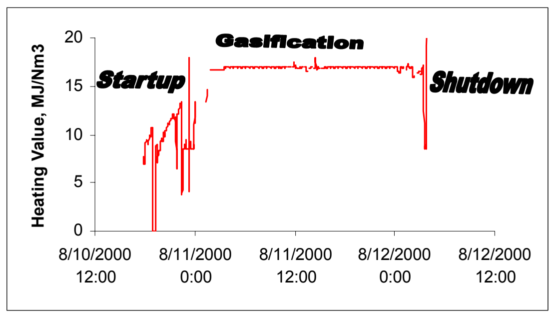

Figure 3: Gas Composition is Consistent

At the Vermont site, both the product and flue gas from the gasification plant are used in the McNeil boiler. As a result, whenever the McNeil boiler operation is interrupted, the gasifier operation must be halted until the boiler is back in service. These interruptions have occurred several times during the current testing program. By encountering such process upsets, we have shown that the entire gasification plant can be restarted within 30 to 45 minutes after an unexpected plant shutdown.

3.4 Gas production rates

Consistency of gas composition provides the foundation for application of the product gas. The other essential element is the gas production rate. PRU testing established a biomass conversion curve that was used to evaluate the performance of the Vermont gasifier. Figure 4 illustrates the gas production rates expressed as a fraction of the incoming wood carbon found in the product gas. The Vermont gasifier data fall well within the data set previously generated in the PRU throughout the operating temperature range tested. Normal operating temperature for the *SilvaGas* process will be in the range of 800 to 850C (1500 to 1550F). As is seen in figure 4, much of the testing in the Vermont plant has been at a somewhat lower temperature than the tests in the PRU due to higher heat losses in the Vermont gasifier. The refractory linings in the

Vermont gasifier were chosen based on their ability to withstand the frequent startup and shutdown cycles typical in a demonstration facility rather than to optimize system heat losses. Improved heat loss characteristics will be specified for the refractory linings in commercial scale facilities.

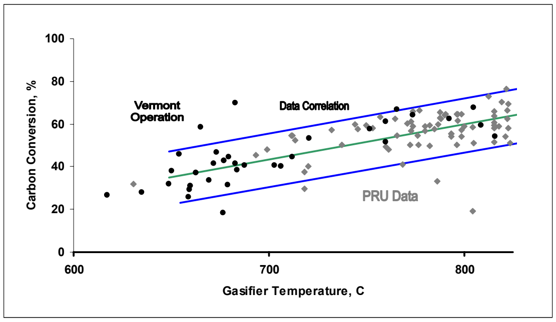

Figure 4: Comparison of Gas Production Rates

4 PLANNED ACTIVITIES

As a part of its current activities, FERCO is evaluating gas conditioning in the Vermont gasifier. These studies focus on both commercially available gas cleanup methods and a proprietary gas cleanup system developed by FERCO and Battelle. This proprietary system has been discussed in previous publications[2]. Preliminary results indicate performance consistent with previous data developed in the PRU. These studies have also demonstrated the ability of the Burlington gasifier to provide smaller quantities of representative product gas for evaluation of other technologies at the site including chemical synthesis, advanced power systems, or hydrogen generation.

Development partners are being added to the program team to provide the necessary expertise in gas compression, and gas turbine power generation.

5 COMMERCIALIZATION ACTIVITIES

FERCO is actively pursuing additional commercial applications of the *SilvaGas* technology. These efforts have resulted in the signing of several commercial project development agreements (JDA's). One project with a major paper producer will gasify paper mill wastes to produce a gas for substitution in the mill's lime kiln and other natural gas users. Another will gasify wood waste and use the gas for direct fuel uses and power generation. Other projects will use prepared MSW, energy plantation crops, or biomass wastes as the feedstocks. A number of other projects are in negotiation and JDA's are expected to be signed in the near future. The FERCO project partners include Jacobs Engineering, several major U.S. utilities, and several international industrial concerns.

A variety of feedstock opportunities are being investigated for these projects. A significant number will use prepared MSW as the feed to the gasifier and provide the resulting product gas to existing landfill gas pipelines, thus augmenting the landfill gas supply. Other projects will use waste biomass resources from municipal or agricultural sources and generate gas that will be used as input to utility or industrial boilers as a co-fired fuel much as is being done in Vermont. In each case the projected economics of these projects is favorable providing reasonable returns to the project investors. In general, these favorable returns can be realized without the need for financial incentives such as tax credits or capital subsidies.

6 CONCLUSIONS

Operation at the McNeil site has validated the performance of the *SilvaGas* gasification process. These development efforts have enabled FERCO to proceed with the development of a number of commercial projects. The performance of the system during testing in the Vermont gasifier has shown that:

- Gas composition and production rates are identical with those projected based on pilot plant testing. Gas heating value of 17-19 MJ/Nm^3 (450 to 500) Btu/scf has been demonstrated for extended operating periods with a constant heating value regardless of changes in feedstock moisture.
- High biomass throughputs can be achieved in compact reactors resulting in favorable process economics. Reactor throughput has been demonstrated to be 150% of design.
- No extensive preparation of the biomass feedstocks is necessary for the process expanding the range of biomass materials that can be used in the process.
- The process is very stable as demonstrated by around-the-clock operational periods utilizing wood feedstocks with moisture contents ranging from 10 to 50+%.
- The process has the ability to rapidly respond to downstream conditions.

7 ACKNOWLEDGEMENTS

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